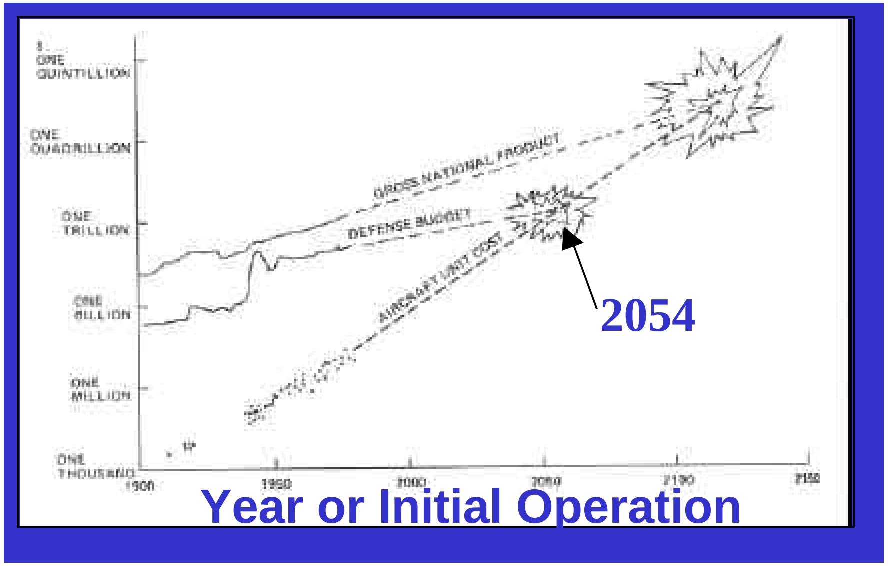
What can SFF do for you ?

Cost Increase 2x Inflation



Augustine's XVI Law: In the year 2054, the entire defense budget will purchase just one aircraft. (no ships or tanks!)

Why does the cost of Defense Systems increase at 2x Inflation?

a. There is no economy of scale (Craft Production)

b. We are willing to pay a premium for an marginal performance increase (the advantage in battle)

c. Political compromise results in smaller than planned buys (Super Hornet, F-22, JSF)

What is the point?

Tool-less Manufacturing positively impact a, b, c

What if we needed no part specific tooling for
component manufacture?

Acquisition: Fly before you buy
Operation & Support: Store spare parts as software
Prototype Development: Cycle time and cost reduced 30X

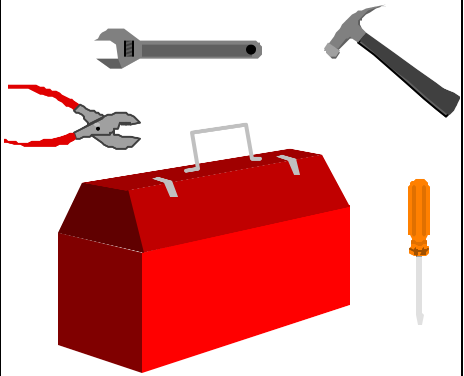
How does this fit in with megatrends?

Virtual Manufacturing / Paperless Design
Internet based Commerce / Agile Manufacturing

Capital for Infrastructure: ~$2B/year for five years ??
(Industrial Machinery & Equipment Market $5 B in CY97)
(RP Equipment Market ~$200M/year, CY97)

Solid Freeform Manufacturing
"Toolbox for the 21st Century Inventor"

Defense Sciences Office



20th Century

Technology-
- Convert virtual objects to solid objects with form, fit and function, and without part specific tooling or operator intervention.
- Reduce prototyping time from months to days for complex components.

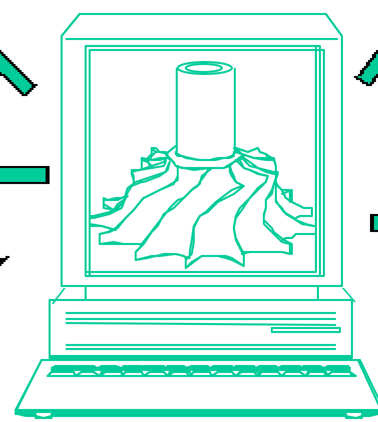
3-D Printing (MIT)
- Ceramics
- Injection Molding Tools
- Casting Molds

Fused Deposition (Honeywell; Lone Peak Stanford/ACR)
- Silicon Nitride
- Plastic Molds
- Electroactive Ceramics

Stereolithography (SRI; U. Mich.; CCI)
- Silicon Nitride
- Alumina
- Porous Metals

Laminate Object Manufacturing (U. Dayton, Javelin, CWRU)
- Ceramic Matrix Composites
- Masters
- Piezo- Acuators

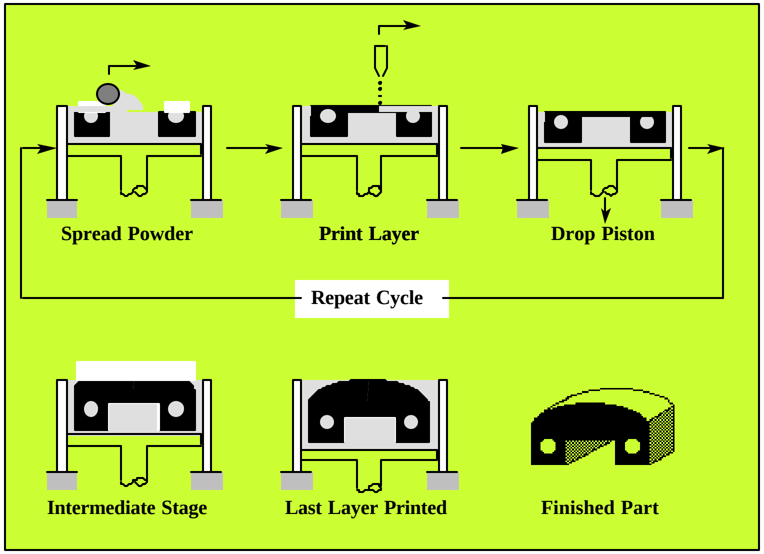
Reverse Engineering
- X-ray tomography (ARACOR)



21st Century

3-D Printing , (MIT)

Defense Sciences Office



Schematic illustration of the 3D printing process. A layer of powder is spread and selectively joined by printing binder. Repeat until full geometry is defined.

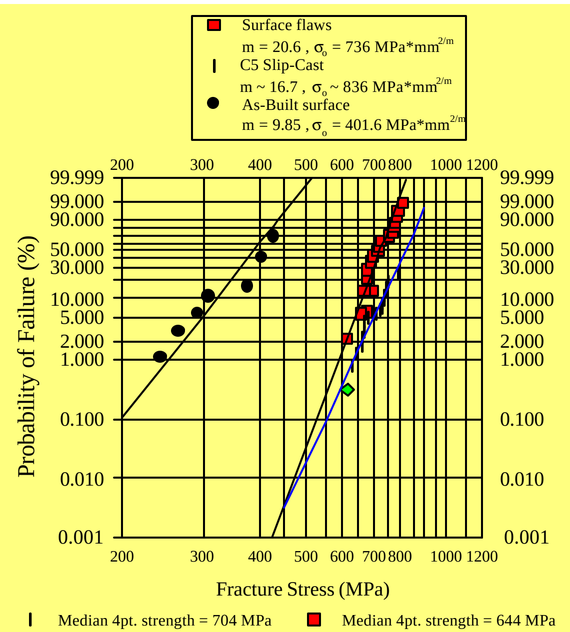
Companies commercializing 3D Printing:

- ExtrudeHone, Corp. of Irwin, PA for tooling and metal parts.
- Z Corp. of Somerville, MA for appearance models.
- Soligen, Inc. of Northridge, CA for ceramic molds for metal casting.
- Therics, Inc. of Princeton, NJ for medical applications.
- Specific Surface Corp. of Franklin, MA. for filters
- MMCC Inc. of Waltham, MA for Metal Matrix Composites
- Kennametal & Valenite, cutting tools
- TDK Corp. (Japan) electronics/ferrites

The fundamental strengths of the process are:

- *Flexibility in Geometry*. Any 3-D geometry with 50 µ feature size can be created.
- *Flexibility in Materials*. Components can be built out of ceramic, metal, or polymeric powders. The composition can be locally controlled by ink-jet printing of different materials.
- *Scalability*. Multiple nozzles can be used to increase the rate of the process.

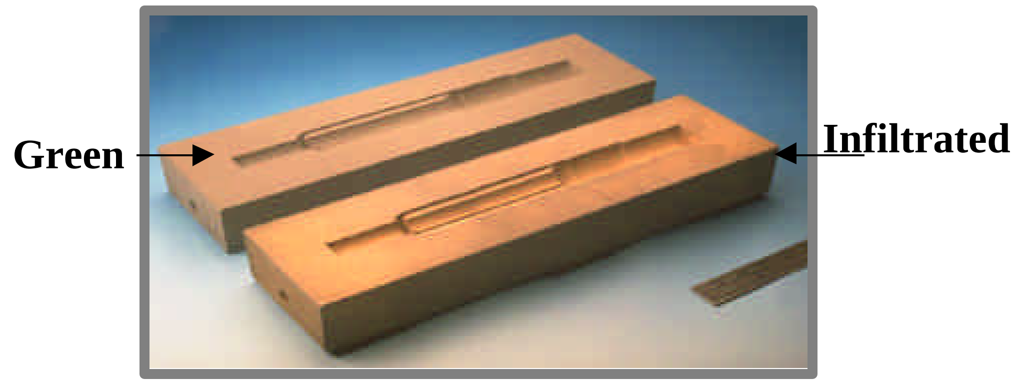
Extrusion Deposition (Honeywell)



- Monolithic JTAGG II Army blade fabricated and sintered; blade with Si_3N_4-30%SiC insert fabricated
- Test bars built for room temperature strength of machined and as-built surfaces
- Multi-material parts (Si_3N_4 and SiC) fabricated
- Blades (monolithic now, insert later) metrology via CMM data analysis. Quantitative data on shrinkage and warpage used for reverse engineering. Can compare to bisque machine process

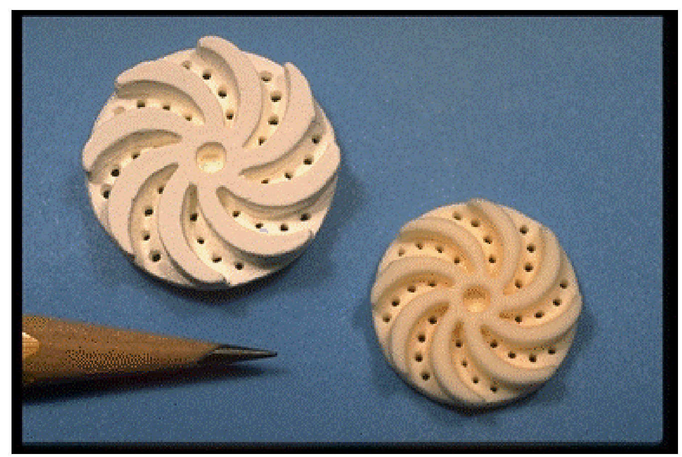
3-D Printing (MIT)

Ceramic Hot Gas filters
Specific Surfaces Inc.



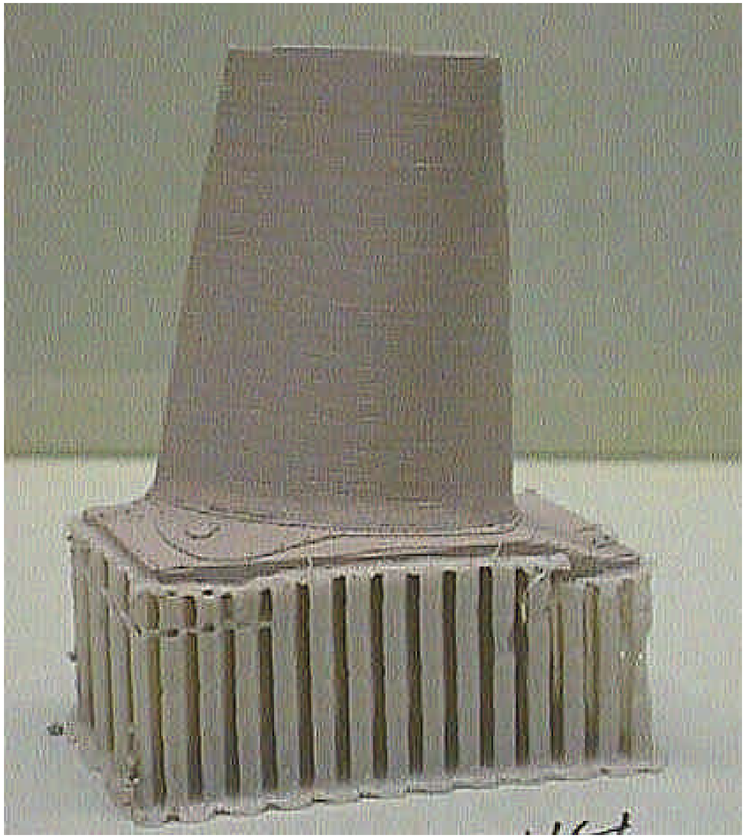
Injection molding tooling with conformal cooling (15% reduced cooling time cycle)

Al_2O_3 turbine vane
printed on slurry deposited layer

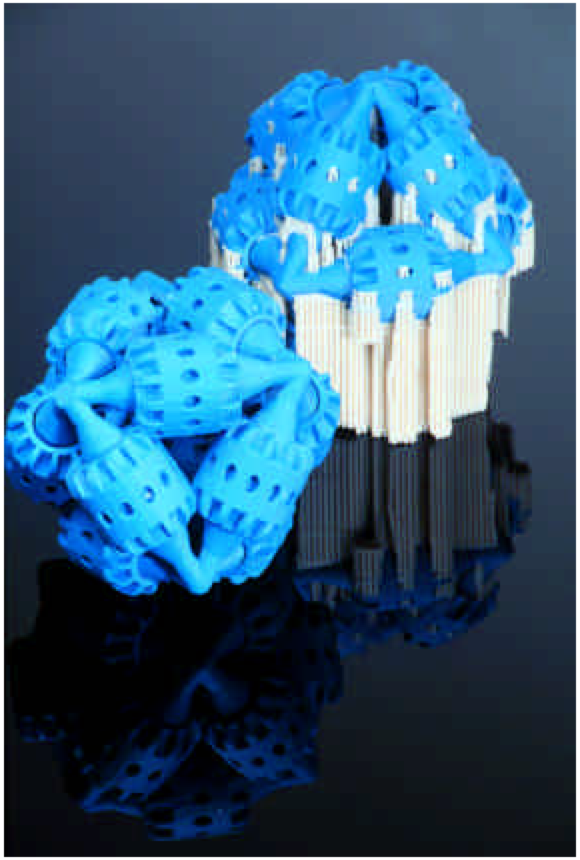


Pin wheel printed on slurry layers

Water Soluble Support (ACR Inc.)

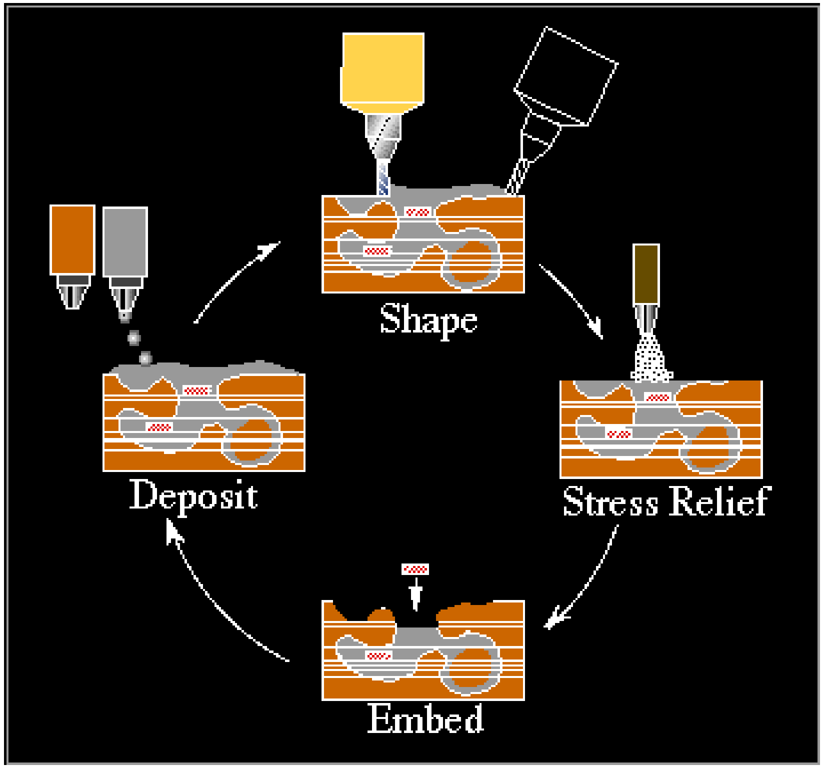


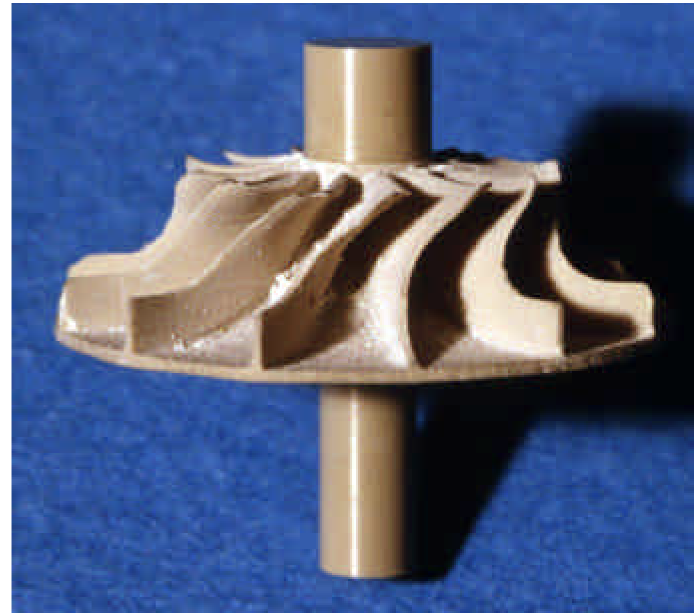
Silicon Nitride Blade, Water Soluble Support Material



ABS Polymer Gear assembly, Made with water soluble support

Shape Deposition Modeling
(Stanford U., CMU, ACR Inc.)



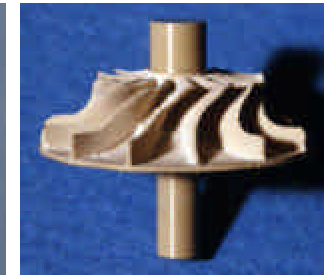


Si_3N_4 turbine for M-Dot micro gas turbine engine

- Turbine rotor features:
  - Diameter: 22 mm
  - 13 blades, min. thickness: 250 µm

Support and build materials are alternately deposited and machined. Either direct parts, or mold for casting parts are produced. Geometry's incompatible with CNC tool paths are possible.

Build Time of Mold SDM Parts

parts / process		Center Seal		Inlet Nozzle		3 Axis Rotor		5 Axis Rotor	
		6 molds	per mold	6 molds	per mold	9 molds	per mold	1 mold	per mold
Mold Fabrication	Machining	2.2 hr	0.37 hr	24.3 hr	4.0 hr	36.5 hr	4.1 hr	16 hr	16 hr
	Deposition	2.6 hr	0.43 hr	11.3 hr	1.9 hr	12.5 hr	1.4 hr	N/A	N/A
	Subtotal	4.8 hr	0.8 hr	35.5 hr	5.9 hr	49.1 hr	5.5 hr		
		0.6 day	**0.1 day**	4.4 day	**0.7 day**	6.1 day	**0.7 day**	3 day	**3 day**
Etching		0.5 day		3 day		5 day		5 day	
After mold processes	Casting	5 day							
	Curing								
	De-molding								
	Drying								
	Debinding								
	Sintering								
Total	one batch	**6.1 day**		**12.4 day**		**16.1 day**		**13 day**	
	N parts	0.1 N + 5.5 day		0.7 N + 8 day		0.7 N + 10 day		3 N + 10 day	

(1 day = 8 hours)

MicroFabrication by CoeXtrusion
Aaron Crumm and John Halloran (U. Michigan)

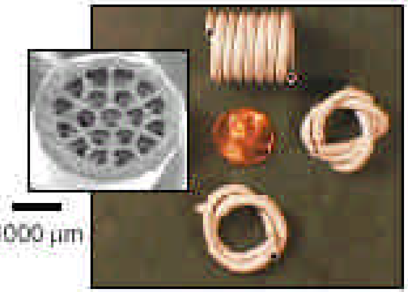
Micro-Channel Structures

Copper Heat Exchanger

300 µm

Honeycomb Tubes

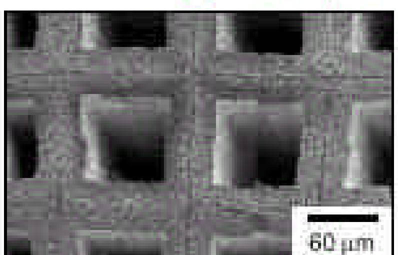
Post Extrusion Forming



1000 µm

Cofired Structures

PMN-PT / AgPd Composite



Fine Scale Fibers

Alumina

25 µm

Summary

- For the Physicists: Consider teaming with organizations which have SFF expertise for fabrication of Meta-Materials.

- For the SFF community: Think about teaming with Physicists. (Particularly if they understand the physics of Meta-Materials)